7. INTRODUCTION TO THE BOEING PROGRAM

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INTRODUCTION

The Boeing Company, under NASA Contract NAS 1-7129, has developed and tested an acoustically treated engine-nacelle concept on the JT3D low-bypass turbofan engine. This treated nacelle was designed to reduce the fan noise components of the turbofan-engine noise. The primary goal of the program was a reduction of perceived noise level of 15 PNdB during landing approach. The basic approach applied in the development of the treated nacelle was the absorption of the fan-generated engine noise by acoustic lining material. A program of analysis, model test, full-scale ground test, and subsequent full-scale flight test on a 707-320B airplane was followed in the development and testing of this nacelle. The acoustic and performance results obtained during testing of the final flightworthy nacelle as well as an economic analysis are discussed in papers 8, 9, and 10. The purpose of this paper is to provide a background of the program studies leading to the final testing. This paper will describe the acoustic material used, the nacelle configuration selected, and the final airplane/nacelle installation.

ACOUSTIC MATERIAL SELECTION

The noise-suppression technique applied in this program was based on the principle of sound absorption in acoustically lined ducts. This approach proved feasible because of the nature of fan-generated noise in turbofan engines. First, the fan noise propagates through the inlet and duct passages before it radiates from the engine. Second, the fan noise consists of discrete high frequency components that are amenable to absorption with acoustical lining. The studies that were conducted to develop an acoustic lining technology for fan noise suppression and the material development part of this program were covered in detail at the NASA conference held in October, 1968. Those studies will not be detailed in this paper. However, one important result from those studies needs to be emphasized to provide a complete story on the acoustic material selection efforts. That is, the acoustic test results on porous surface materials indicated that similar acoustic performance could be obtained from a number of the materials examined, provided the materials were properly selected. Hence, final selection of the material for use as an acoustic duct lining was determined as much by structural qualities as by acoustic characteristics. To aid in this selection, sandwich panels were subjected to high sonic environment tests, aerodynamic flow property measurements, environmental

tests, and weight analysis. Ease of fabrication analysis and maintainability evaluation were carried out as well. The latter evaluation included such items as durability, ease of cleaning, susceptibility to damage from foreign objects entering the inlet cowl, and repair.

The final acoustic material selected by Boeing for application to the JT3D engine was a polyimide fiberglass sandwich consisting of a polyimide-porous fiberglass laminate face sheet, a honeycomb core, and a nonporous laminate backing sheet. (See fig. 1.) This material was developed by Boeing for application as acoustic lining. The porous fiberglass laminate consists of several layers of fibercloth arranged to provide proper acoustic porosity, strength, and minimum surface roughness. The honeycomb core consists of nonporous fiberglass cloth joined to the porous and nonporous laminates with polyimide adhesive. Cell depth of the honeycomb was determined primarily by acoustic considerations. In applying this material to the nacelle, single layer linings were selected for all walls. Attenuation over the required frequency range was achieved by varying the honeycomb cell depth.

Following material selection, further evaluation tests were conducted. Additional sonic environment tests were run with panels subjected to noise levels as high as 160 dB for 25 hours. No fatigue failure or degradation of material properties was evident during these tests. The panels were also subjected to cyclic tests simulating environmental conditions encountered in normal flight. Test parameters included temperature and pressure, moisture, airflow, and noise. There was no measurable change in weight or material properties. In addition, sandwich panels were subjected to water and then frozen. As anticipated, the bond between the porous laminate and the core was broken. However, in order to achieve a panel failure, the core had to be completely filled with water. Moreover, the only way the sandwich could be completely filled was by complete submersion of the specimen in a vacuum chamber.

Although all the items described above were studied in sufficient detail to ensure a successful ground-test and flight-test program, the studies were not extended to develop an acoustic liner for in-service operation. Considerable work is still required in many areas to provide a material and liner for this use. However, acoustic panel service testing is proceeding at Boeing with various material types. To date, polyimide fiberglass panels, a sample of which is shown in figure 2, have been subjected to over 200 hours of operation in the fan duct of JT8D turbofan engines which have been used in both ground and flight operations. Some small bond separations have occurred in the bond line between the acoustic skin and the potted core. Contamination has been very slight. These same panels have experienced no change in acoustic performance.

NACELLE CONFIGURATION SELECTION

After the material was selected, methods of applying the material to the JT3D engine were studied. The existing engine and nacelle are shown in figure 3. Examination of the existing Boeing nacelle on a JT3D engine indicated that substantial changes would be required to achieve the program noise suppression goal. This nacelle has a relatively short inlet with blow-in doors and a very short fan duct that provides little area for acoustic linings. Modifications to this nacelle for noise reduction were investigated. The final treated nacelle configuration selected following a number of conceptual studies is shown in figure 4.

Inlet modifications include a 10-inch extension from inlet lip to compressor face, removal of the blow-in-doors, and acoustic treatment on the inner cowl wall and long inlet centerbody. Two treated concentric rings have been added. These rings are treated on both sides and equally spaced between inlet surfaces. Insertion of the rings divided the inlet into a series of channels or ducts, thus allowing for more effective use of acoustic linings. Unlined ring support struts are located at eight radial positions in the inlet. The treatment lengths in the rings, cowl, and centerbody were selected to provide a uniform noise field across the inlet. The total area treated in the inlet was 71 square feet. This configuration resulted from conceptual studies that included acoustic as well as performance analysis. Of the various designs studied, the concentric ring design provided the best engine performance characteristics for a given noise attenuation.

Fan duct modifications included a full-long extension to the existing nacelle fan ducts. That is, the fan duct was extended to become essentially coplanar with the primary exhaust duct. The acoustically treated areas are located in two separate parts of the duct. The forward section has double-wall lining plus four lined splitters in each duct half. The aft section has outer wall lining only, plus four treated splitters. The duct contour progresses from an elongated kidney design in the forward section to a full annular configuration at the tailpipe. (See fig. 4.) This design provides for minimum duct height, which aids in sound absorption and provides for maximum area for acoustic treatment. Total area treated was 267 square feet. A section of duct between the two acoustically treated sections has been left untreated. This area represents the possible location of a new secondary thrust reverser, made necessary by the redesign of the forward section of the fan duct. The primary jet-thrust reverser is located in the same area as on the existing nacelle. It has been assumed that, by making the double wall nozzle section translatable as is done with the existing single wall nacelle, the primary reverser would require a minimum of rework to remain compatible with the treated nacelle.

The duct design was evaluated for both aerodynamic and acoustic performance. The two-ring inlet and full-long duct provided proper balance of noise suppression for inlet and

fan-duct noise. An additional advantage of long ducts uncovered during preliminary testing was that the jet noise was redirected to provide noise reduction at landing-approach power. Ground-test results obtained on a boilerplate nacelle indicated that the acoustical treatment in the nozzle section did not reduce the noise levels below the levels obtained with the treatment in the forward section only. Nevertheless, a decision was made to treat this area on the flightworthy nacelle in the event that the suppression afforded by the completely treated nacelle as measured in flight might be less than that measured on the ground. The additional nozzle treatment also provided a cushion in case contamination of the treatment might result in loss of acoustic efficiency. Since neither of these events occurred, it is believed that this treatment could be removed without affecting the overall noise reductions afforded by the treated nacelle.

AIRPLANE/NACELLE CONFIGURATION

The nacelle described herein was subjected to both a ground-test and flight-test program. The flight-test portion of the program was conducted on a Boeing 707-320B airplane powered by JT3D turbofan engines. The nacelle installation is shown in figures 5 and 6. An anti-icing system was included for all surfaces in the inlet to aid in evaluating the viability of the treated configuration. This system was ground tested and met all the basic requirements. In addition, positive water drainage was provided from each acoustic panel by circumferential grooves in the core surface. All treatment material in both the inlet and fan duct was frame-mounted and of load-carrying construction. No major strut modifications were required. The treated nacelle did not incorporate thrust reversers. However, as stated previously, space was allotted for their inclusion. No problems were encountered with the nacelle or the acoustic material during the 40 hours of flight testing.

The estimated nacelle weight change required for a potential retrofit version of the treated nacelle, including thrust reversers, is shown in figure 7. Weight increase of the nacelle, including thrust reversers, is estimated to be 3140 pounds per airplane. Although the two-ring inlet and the full-long, full-annular duct provided a flightworthy test nacelle for the JT3D engine installed on the 707-320B airplane, it is not necessarily an optimum retrofit design, nor does it represent a standard design for all turbofan engines. Each engine/airframe type has unique acoustic, installation, and performance problems that must be considered in design of an acoustically treated nacelle for in-service operation. Examination of the 720B and 707-120B airplanes, for instance, revealed that installation of the treated nacelle described herein would require that the outboard nacelle be relocated approximately 15 inches aft and extended downward approximately 4 inches to prevent flutter problems. A new strut would therefore be required.

The acoustic lining technology developed in this program is applicable not only to the JT3D engines, but other turboflow engines as well. However, the noise suppression achieved through application of the acoustic lining technology will be a function of the noise-generating characteristics of the engine and the duct geometry. These will both change significantly with change in engine bypass ratio and/or fan design.

The subject airplane-engine configuration was tested during conditions of static ground operations, ground roll, take-off, climbout, cruise, and landing approach. The evaluation of acoustics, performance, and economics obtained from these tests is presented in papers 8, 9, and 10.

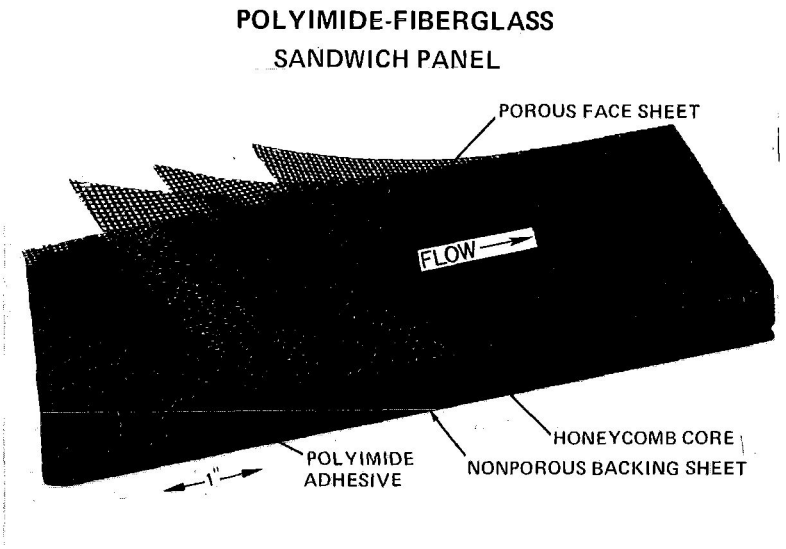

Figure 1.- Acoustic lining for JT3D inlet and fan duct.

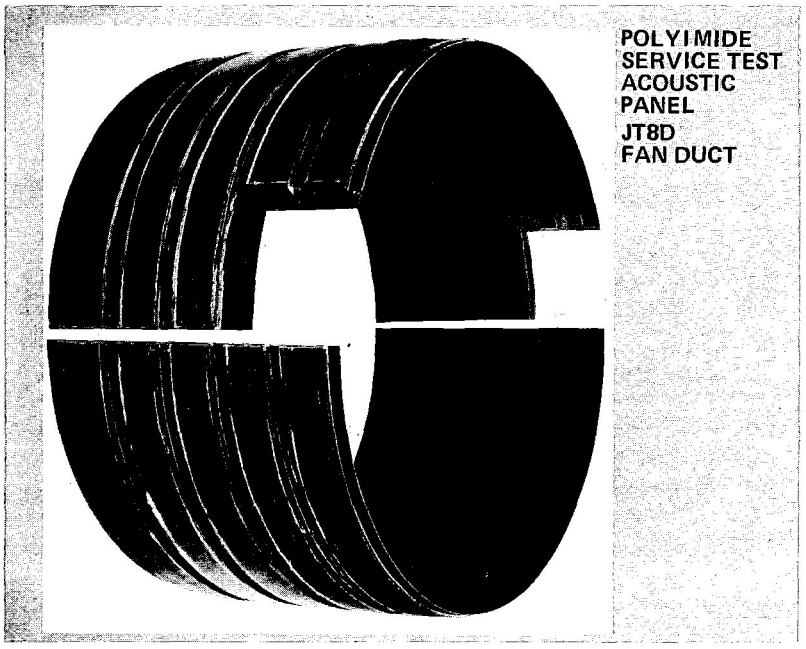

Figure 2.- Environmental test panel for acoustic lining evaluation studies.

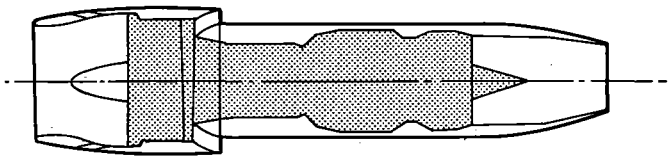

Figure 3.- Existing Boeing nacelle for JT3D engine.

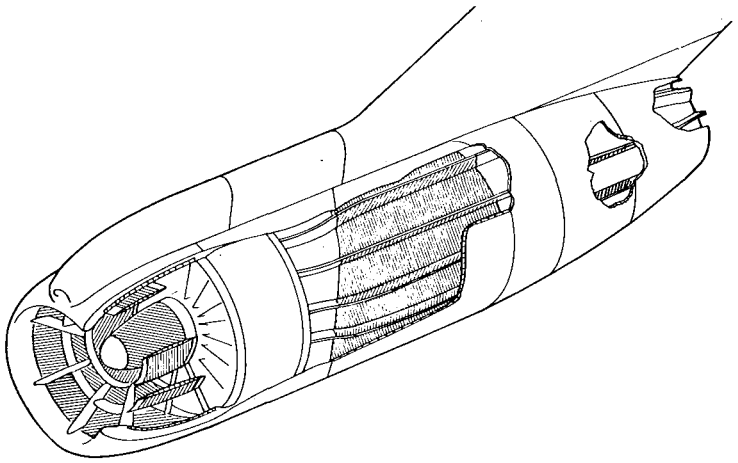

Figure 4.- Boeing JT3D treated nacelle concept.

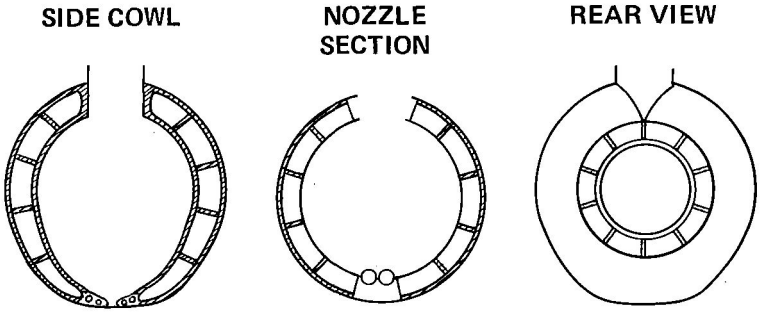

Figure 5.- Treated nacelle duct design.

Figure 6.- JT3D engine/nacelle installation.

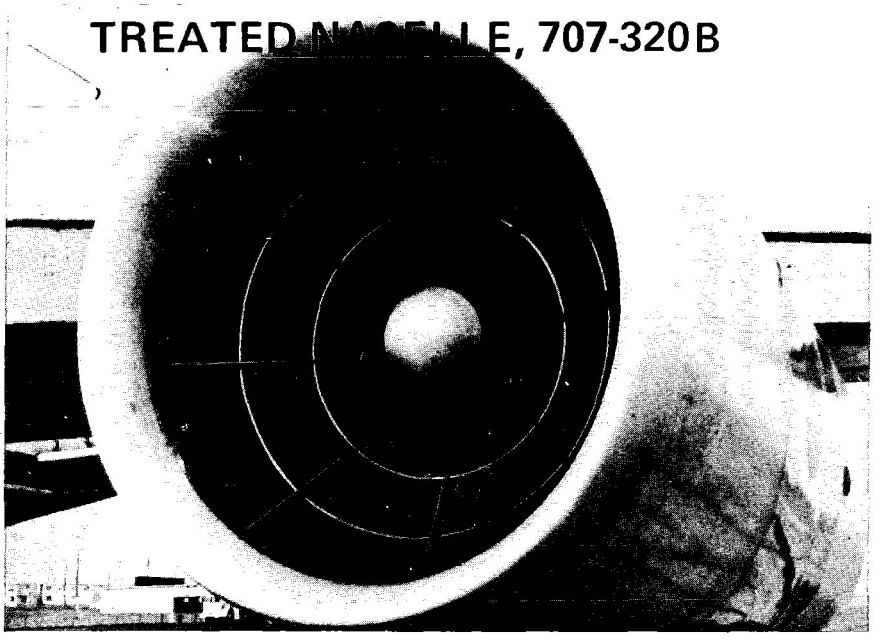

Figure 7.- Acoustically treated JT3D inlet installation.

NACELLE WEIGHT
FOUR NACELLES MINUS ENGINES

EXISTING	7768	lb
REMOVED	3888	lb
ADDED	7028	lb
TREATED	10,908	lb
Δ WEIGHT	3140	lb

Figure 8.- Nacelle weight changes required to provide JT3D acoustically treated nacelle.